LCA Case Studies

System Expansion and Allocation in Life Cycle Assessment of Milk and Beef Production

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DOI: http://dx.doi.org/10.1065/lca2003.07.126

Abstract

Background, Goal and Scope. System expansion is a method used to avoid co-product allocation. Up to this point in time it has seldom been used in LCA studies of food products, although food production systems often are characterised by closely interlinked sub-systems. One of the most important allocation problems that occurs in LCAs of agricultural products is the question of how to handle the co-product beef from milk production since almost half of the beef production in the EU is derived from co-products from the dairy sector. The purpose of this paper is to compare different methods of handling co-products when dividing the environmental burden of the milk production system between milk and the co-products meat and surplus calves.

Main Features. This article presents results from an LCA of organic milk production in which different methods of handling the co-products are examined. The comparison of different methods of co-product handling is based on a Swedish LCA case study of milk production where economic allocation between milk and meat was initially used. Allocation of the co-products meat and surplus calves was avoided by expanding the milk system. LCA data were collected from another case study where the alternative way of producing meat was analysed, i.e. using a beef cow that produces one calf per annum to be raised for one and a half year. The LCA of beef production was included in the milk system. A discussion is conducted focussing on the importance of modelling and analysing milk and beef production in an integrated way when foreseeing and planning the environmental consequences of manipulating milk and beef production systems.

Results. This study shows that economic allocation between milk and beef favours the product beef. When system expansion is performed, the environmental benefits of milk production due to its co-products of surplus calves and meat become obvious. This is especially connected to the impact categories that describe the potential environmental burden of biogenic emissions such as methane and ammonia and nitrogen losses due to land use and its fertilising. The reason for this is that beef production in combination with milk can be carried out with fewer animals than in sole beef production systems.

Conclusion, Recommendation and Perspective. Milk and beef production systems are closely connected. Changes in milk production systems will cause alterations in beef production systems. It is concluded that in prospective LCA studies, system expansion should be performed to obtain adequate information of the environmental consequences of manipulating production systems that are interlinked to each other.

Keywords: Allocation; beef production; life cycle assessment (LCA); methane-emissions; milk production; organic agriculture; system expansion

Introduction

Milk and beef production are the two largest production sectors in the agriculture of the European Union, accounting for 18% and 10%, respectively, of the total value of Community agricultural output [1,2]. The two production schemes are closely interlinked; surplus calves and meat from culled dairy cows are an important base for beef production. In Sweden, as much as 70% of the beef production is derived from co-products from the dairy sector and in the whole EU this figure is approximately 50% [3]. Milk production is therefore a classic example of a multifunction process and one of the most important allocation problems to deal with when performing life cycle assessment (LCA) studies on primary agricultural production.

When analysing multifunction processes it is important to determine to what extent the environmental burdens of these processes should be allocated to the product investigated. The environmental burden is here defined as the resource demand and the emission of pollutants and how these contribute to the potential environmental impact. The International Organisation for Standardisation (ISO) has presented a standard for LCI – ISO 14041, suggesting that the following procedure be used for allocation in multifunction processes [4]:

- Allocation should be avoided, wherever possible, either through subdivision of the multifunction process into sub-processes, and collection of separate data for each sub-process, or through expansion of the systems investigated until the same functions are delivered by all systems compared.
- Where allocation cannot be avoided, the allocation should reflect the physical relationship between the environmental burdens and the functions, i.e. how the burdens are changed by quantitative changes in the functions delivered by the system.
- Where such physical casual relationship alone cannot be used as the basis for the allocation, the allocation should reflect other relationships between environmental burdens and the functions.

It is very rare that multifunction processes can be physically separated into sub-processes and that the subdivision thereby can eliminate the allocation problem [5]. Therefore, to avoid allocation in multifunction processes according to the ISO hierarchy, system expansion seems to be the prime option. The basic idea of system expansion is that there is an alternative way of generating the exported functions, i.e. the co-products. Exported functions are here defined as functions that are generated in the product life cycle studied but uti-

lised in another product life cycle. If data are available for the alternative production of the co-products, the boundaries of the systems investigated can be expanded to include the alternative production of exported functions. Apart from handling the allocation problem, system expansion makes it possible to model the indirect actions, i.e. the effects on the environmental burdens from activities outside the boundaries of the life cycle investigated [6].

This article will present results from an LCA of organic milk production in which different methods of handling the co-products are examined. It will also discuss the importance of modelling and analysing milk and beef production in an integrated way, using a systemic approach, when foreseeing and planning the environmental consequences of manipulating milk and beef production systems which are important components of the Common Agricultural Policy (CAP) in the EU.

1 Definition of Goal and Scope

1.1 Goal of the study

The goal of this study is to compare different methods of handling co-products when dividing the environmental burden of the milk production system between milk and the co-products meat and surplus calves. The methods studied are: i) no allocation (all environmental burdens are allocated to milk); ii) economic allocation; iii) cause-effect allocation regarding feed intake and iv) system expansion. In this article, the results for the impact categories climate change, acidification, eutrophication and the inventory results for energy use, land use and toxicity (pesticide use) are presented for the four different methods of handling co-product allocation.

1.2 Scope of the study

Two systems have been studied in detail. The milk system is the foreground system (the core system), the main product of which is milk and with the inevitable co-products meat from culled cows and surplus calves for further breeding to produce meat. The background system (the extended system) is a beef production system of which the main product is meat and with hides as a minor by-product. The co-products from the milk system, *i.e.* surplus calves and meat from culled cows, can be seen as products entering the background system where they displace production providing the same function. The avoided burdens are the displaced burdens in the extended system (**Fig. 1**).

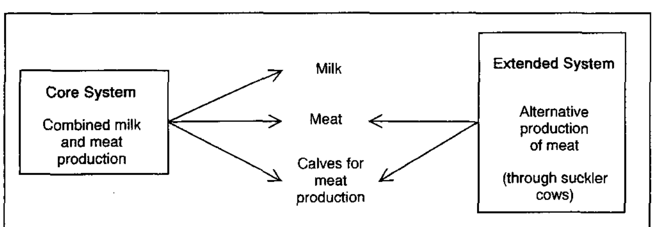

Fig. 1: Principles for system expansion, the alternative way of generating the co-products from the milk system is a beef production system

1.3 System description and boundaries

The study includes production of all input goods to the farming system and all outflow emissions from the system. The geographic border is the farm gate. Production of buildings and machinery is excluded from the analysis.

The milk and beef systems studied are organic according to the eco-labelling system KRAV, which is the sole environmental marking system for organic products in Sweden. In 2000, 3% of Swedish milk production was organically produced and close to 4% of the number of slaughtered cattle. Important characteristics for this form of milk and beef production are:

- Concerning fodder, there are limits for the use of conventionally-produced feed (maximum 5%). On a yearly basis, 50% of fodder (dry matter basis) must be produced on the farm itself. During the grazing period, pasture must be at least half of the total feed intake;
- In the crops, no synthetic fertilisers or pesticides are allowed.

There is a strong political objective to increase organic agriculture in Sweden. The goal of the government is that 20% of the arable land and 10% of the dairy cows, beef cattle and sheep shall be in organic production in the year 2005 [7].

1.4 Functional unit

The functional unit (FU) of the milk production system (the foreground or core system) is one kg of energy corrected milk (ECM) leaving the farm-gate. The FU of the beef production system (the extended system) is one kg of bone-free meat leaving the farm-gate.

1.5 Handling of co-products

Four different ways of handling the co-products surplus calves and meat from the milk system were analysed and examined.

1) **No allocation.** This means that the product milk takes the whole environmental burden of the production system.
2) **Economic allocation.** This was based on average calculations from the Swedish Dairy Association of the yearly income per dairy cow in which the income of the products is divided as 92% for milk, 6% for meat from the culled cow and 2% for the surplus calf.
3) **Cause-effect physical ('biological') allocation.** The base for the so-called 'biological' allocation is the fact that there is a causal relationship between the dairy cow's feed mix and its production of milk, calves and meat. Calculation according to Swedish fodder tables for the supply of energy and protein to cover the dairy cow's milk production, maintenance and pregnancy give an overall allocation of 85% to the product milk and 15% to the meat and surplus calves. This division was based on the official Swedish feeding recommendations as to what proportion of the dairy cow's feed intake is needed for milk production.
4) **System expansion.** Allocation is avoided by expanding the milk system to include the alternative way of producing the co-products from milk production. The alternative way of producing calves for meat production is by beef cows producing one yearly calf and the alternative way of producing meat from the culled dairy cows is a beef production system as shown in Fig. 2.

The prime objective of this study was to discuss the specific effect of different methods of handling the important co-products meat and surplus calves from milk production. Therefore, system expansion was not applied to all allocation situations in the studies. In the milk study, economic allocation was used to distribute the environmental burden from the production of purchased concentrate feed. This feed was mainly rapeseed meal, which is a co-product of rapeseed oil production. The use of purchased concentrate feed was however very small, since the milk system studied is organic with a very high degree of home-produced fodder. In the beef study, economic allocation was used to partition a small part (10%) of the environmental burden to the co-products of meat which have a market and thereby an economic value. These co-products were mainly hides and some intestines.

2 Inventory Analysis

Data for the milk system studied is presented by Cederberg & Mattsson and is representative for a rational organic milk system with good production results [8]. The dairy cows' fodder is clover/grass silage, hay, pasture, barley, peas and minor amounts of purchased concentrate feed. The purchased feed is conventionally produced and represents the part of the feed ration of maximum 5% that is allowed to be non-organic according to the Swedish rules for eco-labelling.

Producing animals in the studied milk system are Holstein cattle, a specialised dairy breed, and the products generated yearly from one cow are shown in **Fig. 2**. The main output product is milk, 7 127 kg energy corrected milk (ECM) per cow leaves the farm-gate yearly. The average calf production is 1.07 calf / dairy cow and year and the average replacement rate is 37% [9]. This means that every year 0.37 heifer calf/ dairy cow has to stay and be raised inside the milk system to replace the culled cows. A culled dairy cow produces 195 kg bone-free meat when it is slaughtered. Since 37% of the dairy cows are culled yearly, the average amount of bone-free meat per dairy cow and year is 72 kg. Yearly co-products from milk production are thus 0.7 surplus calf (for further rearing for producing beef) and 72 kg bone-free meat per dairy cow.

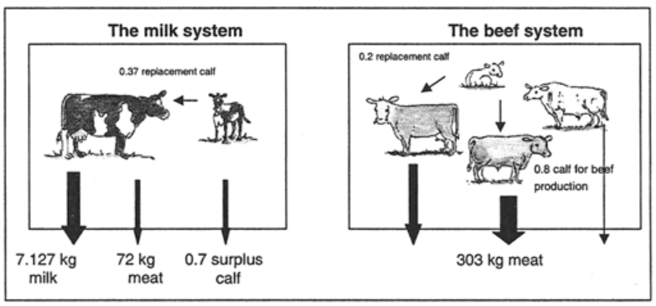

Fig. 2: Yearly products from the milk and beef system

Data for the beef system come from a Swedish study where different forms of beef production systems were analysed [10]. The beef production studied is extensive in the sense that no concentrate feed is used but still representative for organic beef production in Sweden. The cattle have a long grazing period and the stable feeding is based on fodder produced at the farm-site, almost exclusively grass/clover silage of high quality. Although the feed ration was based almost solely on roughage fodder, the growth performance of the beef cattle was good thanks to the high quality of the silage and the pasture.

The mother animals in the beef system are crossbreeds between dairy cattle and meat breeds (e.g. Limousine cattle). The beef cow is mated with a Charolais bull and it gives birth to one yearly calf. The replacement rate is 20% which means that 80% of the calves continue to be reared for beef production (see Fig. 2). The bull calves are castrated and raised as steers and these cattle together with the surplus heifer cattle (not needed for replacement) are the predominant meat producers in the beef system. Also the parent animals generate the output product meat when they are slaughtered. The average culled beef cow (being heavier than a dairy cow) generates 225 kg bone-free meat but since it lives longer than a dairy cow (replacement rate 20%), the average yearly production is 45 kg bone-free meat per beef cow. The bull mates with a herd of several beef cows and therefore contributes very little to the meat production (15 kg). The main meat producer in the beef system, the steer or the surplus heifer, produces an average of 243 kg bone-free meat per animal and year.

Data on production and replacement rate for the cows in the two different production systems are crucial when calculating the reference flow for the system expansion (**Table 1**).

Table 1: Production data for the core system (milk) and the extended system (meat)

Production data	Dairy cow	Beef cow
Delivered milk, kg /year	7 127[a]	0 (all consumed by the calf)
Calf production, no/year	1.07[b]	1
Replacement rate, %	37	20
Calf for meat production	0.7 (1.07–0.37)	0.8 (1–0.2)
Meat[c], kg total / culled cow	195	225
Meat[c], kg /culled cow and year	72	45

[a] Delivered milk at the farm gate. Production was approximately 500 kg higher but this amount was consumed by the calf during its first 8 weeks
[b] The average calf production from dairy cows according to statistics from the Swedish Dairy Association
[c] Bone-free meat

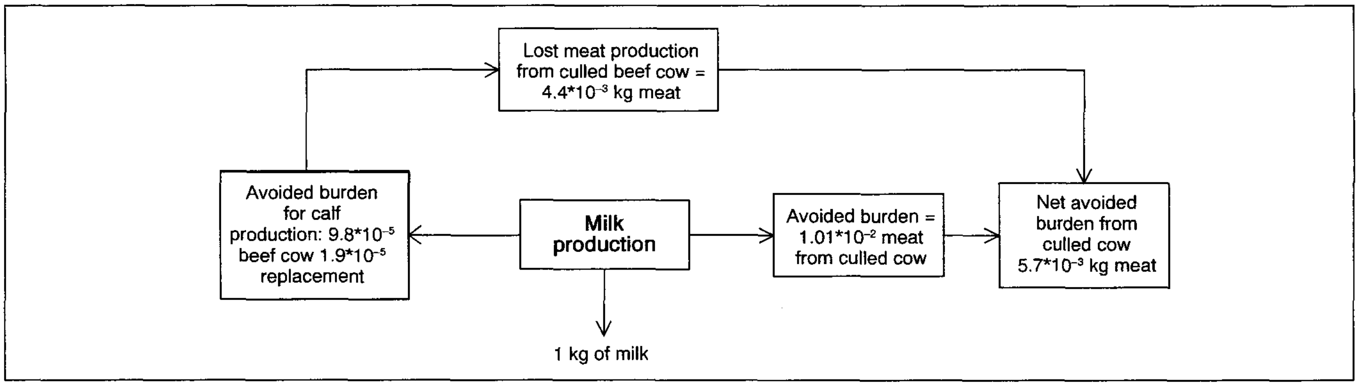

Fig. 3: Reference flows for one kg of milk when expanding the milk system

When the milk system is credited for its co-products according to the production data presented above, the following reference flow is obtained (**Fig.** 3). Due to the outflow of one kg of milk there is an avoided burden in the beef system of 0,0101 kg meat because of the meat production from the culled dairy cows. The surplus calf in the dairy system per one kg of milk corresponds to the avoided breeding of 0.000098 beef cow and its 0.000019 replacement heifer for calf production during one year. However, since there is an avoided breeding of beef cows because of the production of surplus calves in the milk system, there will be a loss in meat production from culled beef cows corresponding to 0.0044 kg meat per kg of milk. The net avoided burden of meat production due to the culling of cows is therefore 0.0057 kg meat per kg of milk.

Finally, **Table 2** shows the characterised unallocated results from the two LCA studies of organic milk and beef production for the impact categories that are discussed in this article as well as the inventory results for secondary energy used in the systems. The greenhouse gases are weighted into CO_2-equivalents at a time horizon of 100 years [11]. The potential acidification and eutrophication are calculated from maximum scenarios according to Lindfors et al. [12]. The potential toxic effects due to pesticide use was no characterised but only reported as use of pesticide (active substance).

The summarised use of secondary energy includes, as described in [8] and [10], direct and indirect use of fossil fuels and electricity throughout the respective lifecycles.

3 Results

Table 3 shows the partitioning of the environmental burden to milk with the different methods of handling co-products and how it is distributed for the impact categories studied.

Energy use. Energy is the only impact category for which the distribution between milk and meat is similar between the mono-functional allocation methods and system expansion. However, when studying electricity solely, 97% of the energy use is partitioned to the milk when avoiding allocation through system expansion. The reason for this is that modern milk producing systems are highly dependent on electricity for the milking and feeding equipment, manure handling and ventilation. The beef production studied is a very low mechanised alternative in which electricity is used only for lighting during the stable period and fencing in the grazing period. The stables are unsophisticated, providing the animals shelter from wind and rain, and manure handling is done with a loader. These are the normal conditions for this type of extensive beef production with a long grazing period.

Table 2: LCIA results (unallocated) for organic milk production and beef production at the farmgate

LCIA results	Milk, per kg ECM	Beef, per kg bone free meat
Energy use, MJ	3	25.9
Land use, m^2 x year	4	78
Pesticide use, mg active substance	12.6	0
Climate change, kg CO_2-equiv.	1.05	22.3
Acidification, mol H^+	0.58	14
Eutrophication, kg O_2-equiv.	0.35	8.2

Table 3: Distribution (%) of environmental burden to milk with different ways of handling co-product allocation

Burdens	No allocation = 100	Economic allocation	'Biological' allocation	System expansion
Energy	100	92	85	87
Land use	100	92	85	66
Pesticide use	100	92	85	100
Climate change	100	92	85	63
Acidification	100	92	85	60
Eutrophication	100	92	85	60

Land use. When studying the yearly use of land occupied by milk production with the different methods for handling the co-products, the picture differs from that of energy use. The outcome of system expansion is that a considerably lower land use should be ascribed to milk compared to the traditional mono-functional allocation alternatives. The reason for this is that the beef system is a production form of meat that requires large land areas. The surplus calf production in the milk system displaces calf production from beef cows and this explains approximately 70% of the lower land use in the system expansion alternative, while 30% is explained by the meat production from the culled dairy cow. However, when studying the type of land use, it is only for grassland (leys and pasture) in which the distribution is considerably lower for milk in the system expansion alternative. Land for growing peas, barley and concentrate feed (feed components used solely in the milk system), is assigned to this system only. System expansion illustrates what type of land use is really necessary for milk production; this is not revealed when using traditional allocation methods.

Pesticide use. Avoiding allocation by system expansion gives the correct picture of the milk system's potential toxicity due to the use of pesticides since the whole environmental burden is ascribed to the product milk (see Table 3). No pesticides were used in the fodder crops in the beef system while the maximum level of conventionally grown concentrate feed (5%) was used in the milk system. Using high-quality conventional protein feed to optimise the dairy cows' yield is a common measure in Swedish organic milk production. To properly describe the potential toxicity impact of milk production, the whole burden of pesticide use must be ascribed to the product milk and not to the exported co-products. If conventional milk and beef production had been studied, the result had however been different, since the use of concentrate feed (and thereby pesticides) are common in conventional beef production in Sweden.

Climate change. When allocation is avoided through system expansion barely two-thirds of the greenhouse gas emissions are ascribed to the milk system (**Fig. 4**). A deeper examination of the methane emissions due to the cattle's enteric fermentation in the two production systems explains this result. In the inventory analysis of the two case studies, methane emissions were calculated thoroughly taking into account important parameters such as production level, fodder consumption and feed quality. The emission factors used for the enteric fermentation corresponded to methane losses of 7.1–7.7% of the cattle's Gross Energy Intake (GEI) [10]. Methane losses from grazing dairy cows at New Zealand have been measured at 6.16% (+/-0.15) of GEI [13]. Kirkpatrick et al. have measured methane losses from cross-bred steers varying between 5.3–8.0% of GEI [14]. The emission factors used in this study is thus in the higher range which can be explained by the feed quality since roughage fodder is a very large part of the total feed ration because of the rules for organic production. The dairy cow's emission were estimated at 150 kg CH_4/yr, of which 130 kg was due to enteric fermentation, 20 kg from manure management and another 58 kg CH_4/year from the replacement heifer. These emissions were apportioned to the main product 7 127 kg milk and the co-products 72 kg meat as well as 0.7 surplus calf. The beef cow was calculated to emit 90 kg CH_4/yr which was apportioned to 0.8 calf and 45 kg meat from the culled cow. The beef calf raised as a steer for one and a half year was calculated to emit a total of 96 kg methane during its lifetime to produce 243 kg bone-free meat. When studying methane emissions from ruminants in relation to the products that the animals actually generate, the benefits of combined milk and meat production become obvious. Also the burden of nitrous oxide on milk is significantly reduced when the milk system is expanded (see Fig. 4). Emissions of nitrous oxides are closely connected to the nitrogen cycle and, similar to the case for methane, meat production as a co-product of milk entails fewer animals and thus less manure handling and less fertilising of fodder crops. Consequently the milk production system must be credited for the avoided burden of nitrous oxide losses in beef systems.

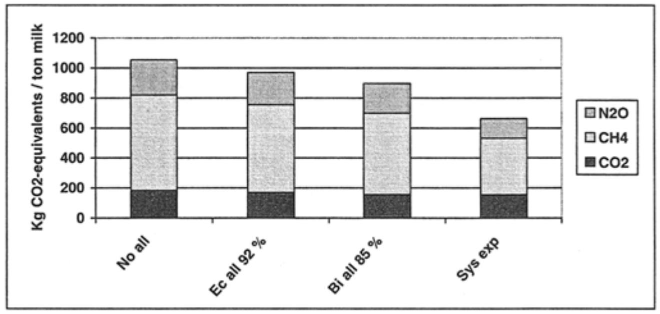

Fig. 4: Emissions of greenhouse gases from milk production with different ways of handling co-product allocation

Acidification and eutrophication. Ammonia from manure is the dominant source of potential acidification and next to nitrate emissions the most important contributor to potential eutrophication. In the system expansion alternative, only 60% of the burden for these two impact categories was allocated to the milk. One explanation for the considerable reduction of the milk's share of ammonia emissions is the manure handling in the extended beef system, which was deep straw litter that gives high NH_3 emissions in contrast to the slurry system in the dairy production, a manure system that has much lower ammonia emissions. However, these conditions are typical for the Swedish manure handling system where dairy farms use slurry to a much higher degree than other cattle farms [15]. Irrespective of manure system, the co-products from milk production lead to an avoided burden of ammonia and nitrate emissions from beef production since fewer cattle are needed to produce the same functions.

There is a large variation in how beef is produced, from low-intensive grazing systems to very intensive systems purely based on feeding in stables with considerable amounts of concentrate feed. This large variation in production methods is mainly influencing the use of energy, land and pesticides in an LCA of beef. In this study, a low-intensive organic beef production system was used as the extended system and this choice of production system has an impact of the result, especially for the impact categories energy use, land use and toxic effects (pesticide use). However, this study of different methods of handling co-products shows that it

is the distribution of biogenic emissions from animals (methane and ammonia) and nitrogen losses due to land use and its fertilising (nitrate and nitrous oxide) that show the largest differences when system expansion is compared with traditional allocation methods.

4 Discussion

It is highly relevant to discuss the issue of co-product allocation when studying complex food production systems, since these systems are often characterised by closely interlinked sub-systems. Milk and meat are in focus in this paper; other important allocation examples in the milk chain are the production of vegetable oils generating protein meal as a co-product. Co-products from vegetable oil production are very important ingredients in concentrate feed production, not only in the dairy sector, but also in all animal production. The results presented in this paper show that the choice of allocation methodology for handling the major co-products meat and surplus calves has a decisive impact on the results of LCAs of milk production. Another interesting finding is that when performing system expansion, the distribution of the environmental burden to milk and its co-products varies significantly between different impact categories.

Weidema argues that co-product allocation should always be avoided in favour of system expansion in prospective LCA studies [16]. In light of the results presented here and elucidated in the following discussion on the development in the Swedish cow population, one must fully agree with this assertion. During the 1990s there was a sharp increase in milk yield among dairy cows in Sweden, resulting in a drastic decline in the number of dairy cows. Almost the same amount of milk (–4%) was produced in 2000 as in 1990 but with 148 000 fewer dairy cows, a reduction of more than 25% (**Fig.** 5) [17]. To compensate for the loss of meat production from a smaller stock of dairy cows, great changes have occurred in the alternative beef production systems. The number of beef cows has increased dramatically (+ 93 000 animals) during the period in order to give birth to calves to compensate for the lost production of surplus calves from the milk sector. Beef imports have also shown an increase. The overall effect of these changes is very complex to analyse but can be illustrated with a discussion on methane emissions due to enteric fermentation from the milk sector. In terms of milk production per se, milk was produced at

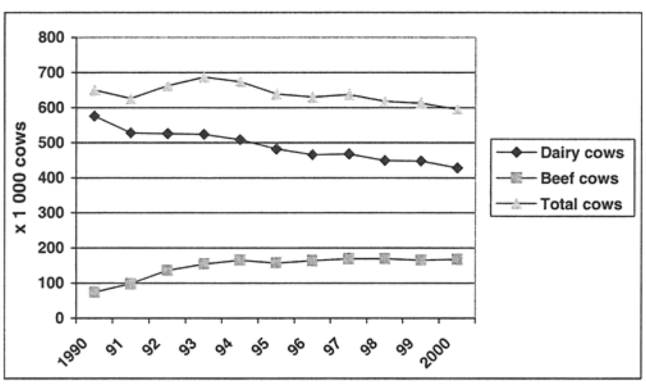

Fig. 5: Development in cow population in Sweden during the 1990's

the end of the 1990s with methane emissions that are 15–18% lower per kg milk due to the reduction in livestock compared with the beginning of the decade [18]. However, the overall effect on methane emissions, i.e. whether the total methane emissions from the milk and beef production have actually decreased, is not easily determined. Since beef consumption has not decreased but has actually increased during the latter part of the decade, more meat is now produced in pure beef production systems. This can be seen in the statistics by the large increase in the number of beef cows but also by the increase in beef imports which probably to a large extent come from pure beef production systems.

In view of this, the on-going specialisation of milk production can be questioned. Martin & Seeland [19] have calculated the effects of specialised milk production based on high milk-yielding cows for the emissions of CH_4, N and P. To replace the loss of meat production due to fewer dairy cows, more beef cows are needed at a constant level of meat consumption. According to Martin & Seeland, the emissions per kg protein (milk+meat) are unchanged or even slightly increased when an increased number of beef cows are needed to compensate for fewer dairy cows. The question arises: what will happen to the Swedish cow population in the coming ten years? All prognoses foresee that milk yield per cow will continue to increase, thus resulting in a further reduction in the dairy cow population since there is a milk quota system regulating the total milk production. From an environmental point of view, it is important to consider not only the effects this development has on beef production but also the marginal effects of the on-going increasing milk yield per dairy cow. One precondition for the increasing milk yield in Sweden during the 1990s has been a substantial increase in the use of concentrate feed. During the period, the amount of purchased concentrate feed has increased by 50% per dairy cow while the consumption of roughage feed has decreased [20]. Refsgaard et al. show that milk is produced at a lower energy cost when the production is based on fodder produced at the farm site, than it is when using feed which has been imported to the farm [21]. A large part of pesticide use in conventional milk production was shown to emanate from the concentrate feed since there is a substantial pesticide application in the crops providing these feed components [8]. A Danish study shows that N-surplus per ton milk at the farm level increases when going from an average feeding intensity to an increased feeding intensity, i.e. when more concentrate feed is used [22]. A number of environmental effects thus arise when already high-yielding cows are to further increase their production since it is mainly concentrate feed that gives rise to this marginal production.

A far-reaching intensification of milk production has environmental effects in milk production systems as well as beef production systems. The environmental cost of marginal milk production from already high-yielding dairy cows can be considerable due to the increased need of concentrate feed at high yield levels. With a lower number of dairy cows and at a constant beef consumption level, more meat will have to be produced using beef cows as mother animals. It is obvious that the overall environmental effects of changes in cow population and milk yield intensity in the dairy sector

have to be studied in an integrated manner. System expansion is the only alternative which handles co-product allocation that will give adequate information to foresee the true effects of these changes. Since both the milk and the beef sectors are on the receiving end of the economic subsidies within the Common Agricultural Policy (CAP) in the European Union, it is of public interest that the political measures to change milk and meat production into a more environmentally friendly direction are based on analyses of the interlinked nature of these two production sectors.

5 Conclusion, Recommendation and Perspective

Milk and beef production systems are inter linked like communicating vessels. Changes in milk systems will cause alterations in beef production systems. Therefore, the choice of allocation method between milk and meat has a decisive impact on LCAs of milk production and it is obvious that a monofunctional allocation approach gives limited information on how to develop and change milk and beef production in an environmentally friendly way. Biogenic emissions, e.g. methane, ammonia and nitrous oxide, should to a lower degree be ascribed to milk production systems than economic allocation tells us. The reason for this is that meat production in combination with milk can be carried out with fewer animals than in a sole beef production system. Besides reducing biogenic emissions, meat production in combination with milk production also means that less land needs to be occupied.

The indirect action of, for example, increased milk yield per dairy cow or increased replacement rate will change the environmental burdens outside the life cycle of milk because beef production systems will be affected. To obtain accurate information about the indirect effects in the beef systems, the relationship between the two systems needs to be accurately modelled. It is evident from this study, that in order to obtain a comprehensive picture of the environmental effects of milk and beef production, the two systems must be studied in an integrated manner. System expansion to handle the allocation issue of the co-products meat and surplus calves should be used when analysing the environmental consequences of changes in future milk production systems.

Acknowledgements. We would here like to convey our thanks to Kristina Darelius, Plönningegymnasiet, Harplinge and Cindy Raaphorst, Animal Production Systems Group, Wageningen University for all their help and assistance in the LCA study of beef production.

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Received: January 3rd, 2003
Accepted: July 21st, 2003
OnlineFirst: July 23rd, 2003